TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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Washington
February, 1932

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With the wide acceptance of the gear-driven supercharger as standard equipment for aircraft engines, it is so easy to obtain almost any desired increase in power by increasing the supercharger gear ratio, that the problem of increasing power has been merely one of making an engine that will stand up under the conditions of operation. Unfortunately, the problem of obtaining reasonable fuel consumption with such "boosted" engines is not so simple.

Many engineers have been interested in the possibility of obtaining increased power from supercharged engines by filling the clearance volume with combustible mixture by means of the available difference in intake and exhaust pressures. To accomplish this, it is necessary merely to allow the exhaust valve to remain open later, and to open the intake valve earlier in order that there shall be a considerable period at the end of the exhaust stroke when both valves are open to permit the charge to flow through.

The purpose of this investigation is to determine with a fair degree of approximation the possible improvement in performance by using a large amount of valve overlap on a supercharged engine. If it were possible to scavenge the clearance space completely, we would expect an increase in the indicated horsepower equal to $1/CR$. As in the two-cycle engine, complete scavenging is not possible since there will always be mixing of the fresh charge with the exhaust gas. Consequently, this figure should be taken as the maximum increase obtainable in the ideal case. If the fuel is mixed with the air outside the cylinder and if any considerable degree of scavenging is obtained, a considerable quantity of fuel is almost certain to escape through the exhaust valve. However, with fuel injected directly into the cylinder, it is possible to delay the injection of fuel until after the exhaust valve has closed and therefore a reasonable fuel consumption can be maintained with a high degree of scavenging.

A series of tests was made on the N.A.C.A. universal single-cylinder engine of 5-inch bore and 7-inch stroke with varying amounts of overlap from 0 to 100° at five different intake pressures. Air was supplied under pressure to the engine from a separately driven Roots type supercharger. A 55-gallon drum was interposed between the supercharger and the engine to provide a receiver from which the engine could draw its charge. The connection between the engine and the drum was made short in order to reduce the effect of pulsations in the inlet pipe. In all tests except those for determining the highest useful compression ratio, which were made some time ago, the engine was fitted with a fuel-injection system consisting of a Bosch pump and a specially constructed nozzle in the cylinder. The injection system has been described in the S.A.E. Journal of the Society of Automotive Engineers, for March, 1931. The injection was timed to start 50° after top center on the suction stroke. Figure 1 is a photograph of the set-up. The air was measured at the inlet to the supercharger by means of a calibrated orifice. Fuel was measured by a volume gauge. Power was absorbed by a directly connected electric dynamometer and all other measurements necessary for complete performance tests of the engine were made. The valve timing was as follows:

Overlap	Inlet open	Exhaust close
0°	T.C.	T.C.
20°	10° B.T.C.	10° A.T.C.
40°	20° B.T.C.	20° A.T.C.
60°	30° B.T.C.	30° A.T.C.
80°	40° B.T.C.	40° A.T.C.
100°	50° B.T.C.	50° A.T.C.

Inlet close 60° A.B.C.
Exhaust open 60° B.B.C. } for all tests.

The lift curves of the valves with varying amounts of overlap are shown in Figure 2. All tests were made at 1500 r.p.m. and at a compression ratio of 4.0 to 1, which was low enough to insure that there was no detonation in any of the tests.

For each setting of the valve timing and each supercharger pressure, the mixture ratio was varied. Curves of b.hp versus fuel flow were plotted and maximum b.hp and the rate of fuel flow for 98 per cent maximum b.hp was taken from these curves. From these data the curves in Figures 3, 4, 5, and 6 were plotted.

Figure 3 shows the net i.m.e.p. at the mixture ratio for maximum power plotted against overlap. It will be noted that the curve representing a manifold vacuum of 3 inches of mercury peaks at about 50° overlap, while at atmospheric pressure the maximum power occurs at 70° and at 3-inch pressure the peak occurs at 100° overlap. At 6-inch and 12-inch pressure the range of the valve gear was not sufficient to find the peak in power. It will be noted that at 6-inch and 12-inch manifold pressure there is an available gain in indicated power of 9 per cent by increasing the overlap from 50° to 100° with further gains available with greater overlap.

From Figure 4 it will be seen that the net indicated specific fuel consumption for all supercharger pressures is approximately the same and the best indicated efficiency is obtained at about 40° overlap. Due to the improvement in mechanical efficiency the net brake specific fuel consumption is lower at the higher manifold pressures and best economy is obtained at a larger value of overlap (50° to 70°). owing

Figure 5 shows an increase in specific air consumption with overlap greater than 40°, with all supercharger pressures. This indicates a loss of fresh air through the exhaust valve. If the engine were fitted with a carburetor giving a constant fuel-air ratio, the specific fuel consumption curves would, of course, be of exactly similar shape. Since the fuel is injected after the closing of the exhaust valve, there is a variation in the apparent fuel-air ratio for 98 per cent maximum power as shown in Figure 6. This indicates a loss of fresh air with the exhaust with overlaps greater than 40°.

Figure 8 shows the variation in volumetric efficiency with overlap. The volumetric efficiency is based on air at manifold pressure and temperature and is corrected for the compression by the incoming charge of the residual gas in the clearance volume. These curves show very clearly the increase in air flow at high values of overlap. It will be noted that the curves intersect near two inches manifold vacuum, which is approximately where the ordinary unsupercharged engine operates at full throttle. Consequently, the effect of overlap on such engines is likely to be very small.

In Figure 8 it will be noted that with no pressure difference between intake and exhaust, there is still an increase in volumetric efficiency with increased overlap. This is undoubtedly due to pulsations and inertia of the gases in both the intake and exhaust pipes. It might be well to state here that the effect of pulsations depends chiefly upon the r.p.m., the length and diameter of the intake pipe, and the number of cylinders connected to one pipe. Tests such as these made on a single-cylinder engine are only indicative of the trends and the orders of magnitude of the results which may be expected with a different engine or a different set-up. To determine optimum valve timing, each engine must be tested individually with the complete intake and exhaust system it is to have in service.

An earlier set of runs, with a carburetor fitted to the engine was made at a supercharger pressure of 6 inches and at varying compression ratio. The compression ratio which gave incipient detonations was 4.3 for 100° overlap and 4.5 for 0° overlap. There was a 16 per cent increase in the power output with the higher value of overlap.

Figure 9 shows the effect on specific fuel consumption of increasing the brake mean effective pressure by increasing the supercharger pressure and at the same time lowering the compression ratio enough to prevent detonation. The effect of increasing the b.m.e.p. by increasing the valve overlap is shown on the same sheet. It will be seen that when the b.m.e.p. is increased to 139 per cent of the normal unsupercharged value by increasing the supercharger pressure and lowering the compression ratio without changing the valve timing, the fuel consumption is increased to 126 per cent of the normal value. If the overlap is increased to 100° it is possible to obtain the same power with a specific fuel consumption only 117 per cent of the unsupercharged value. The better economy in the latter case is chiefly due to the fact that it is not necessary to employ so high a supercharger pressure and consequently the compression ratio can be raised from 3.5 to 3.9 without causing detonation.

The objection usually raised to large amounts of valve overlap is that it interferes with the idling characteristics of the engine. When an engine with valve overlap is throttled, a reversal of flow takes place at the end of the exhaust stroke, the exhaust gas being sucked into the inlet manifold and exhaust gas or air being drawn in through the exhaust valve. Whether exhaust gas or air is taken into the cylinder through the exhaust valve depends upon the length and diameter of the exhaust pipe. If the pipe is not sufficiently long, too much air will be drawn into the cylinder, and it will be impossible to make the engine idle properly without stratifying the charge or resorting to some other means of reducing the power output, such as retarding the spark. It might be possible to make such an engine idle by providing a separate throttle close to each inlet valve. Perhaps the easiest way to obviate the difficulty is to provide a long enough exhaust pipe so that no fresh air will be drawn into the cylinder. The laboratory set-up had such a pipe and the engine would idle at 200 r.p.m. with any valve timing used in the test.

BIBLIOGRAPHY

Schey, Oscar W., and Biermann, A. E.: The Effect of Valve Timing upon the Performance of a Supercharged Engine at Altitude and an Unsupercharged Engine at Sea Level. T.R. No. 390, N.A.C.A., 1931.

De Juhasz, K. J.: Manifold Phenomena in Internal Combustion Engines. Bulletin No. 7, University of Minnesota, Engineering Experiment Station, Vol. 33, No. 45, October, 1930.

Capetti, Antonio: Effect of Intake Pipe on the Volumetric Efficiency of an Internal Combustion Engine. T.M. No. 501, N.A.C.A., 1929.

Ware, Marsden: Description of the N.A.C.A. Universal Test Engine and Some Test Results. T.R. No. 250, N.A.C.A., 1927.

De Juhasz, K. J.: Inlet and Exhaust Phenomena. Experiments Carried Out at High Speed with a Special Indicator. ~~The~~ Auto~~mobile~~ ~~Engineer~~, Vol. XVI, No. 220, 1926, pp. 369-373.

Massachusetts Institute of Technology,
Cambridge, Mass., December, 1931.

APPENDIX

Explanations of terms and calculations

Gross b.hp, = brake horsepower.
Net b.hp, = brake horsepower minus supercharger hp.
Gross b.s.f.c., = brake specific fuel consumption.

$$= \frac{\text{lb. fuel/hr.}}{\text{gross b.hp}}$$

$$\text{Net b.s.f.c.} = \frac{\text{lb. fuel/hr.}}{\text{net b.hp}}$$

$$\text{Net indicated s.f.c.} = \frac{\text{lb. fuel/hr.}}{\text{net b.hp + friction hp}}$$

$$\left.\begin{array}{l}\text{Net indicated specific}\\ \text{air consumption}\end{array}\right\} = \frac{\text{lb. air/hr.}}{\text{net b.hp + friction hp}}$$

$$\text{Supercharger horsepower} = \frac{144\ P_1\ V_1}{e}\ \frac{K}{K-1}\left(\left[\frac{P_2}{P_1}\right]^{\frac{K-1}{K}} - 1\right)$$

P_1, = pressure at intake to supercharger, lb./sq.in.

P_2, = supercharger pressure, lb./sq.in.

$K = 1.4$

$e = 0.70$

$$\text{Supercharger m.e.p.} = \frac{792000\ \text{supercharger hp}}{D \times N}$$

D, = engine displacement, cu.in.

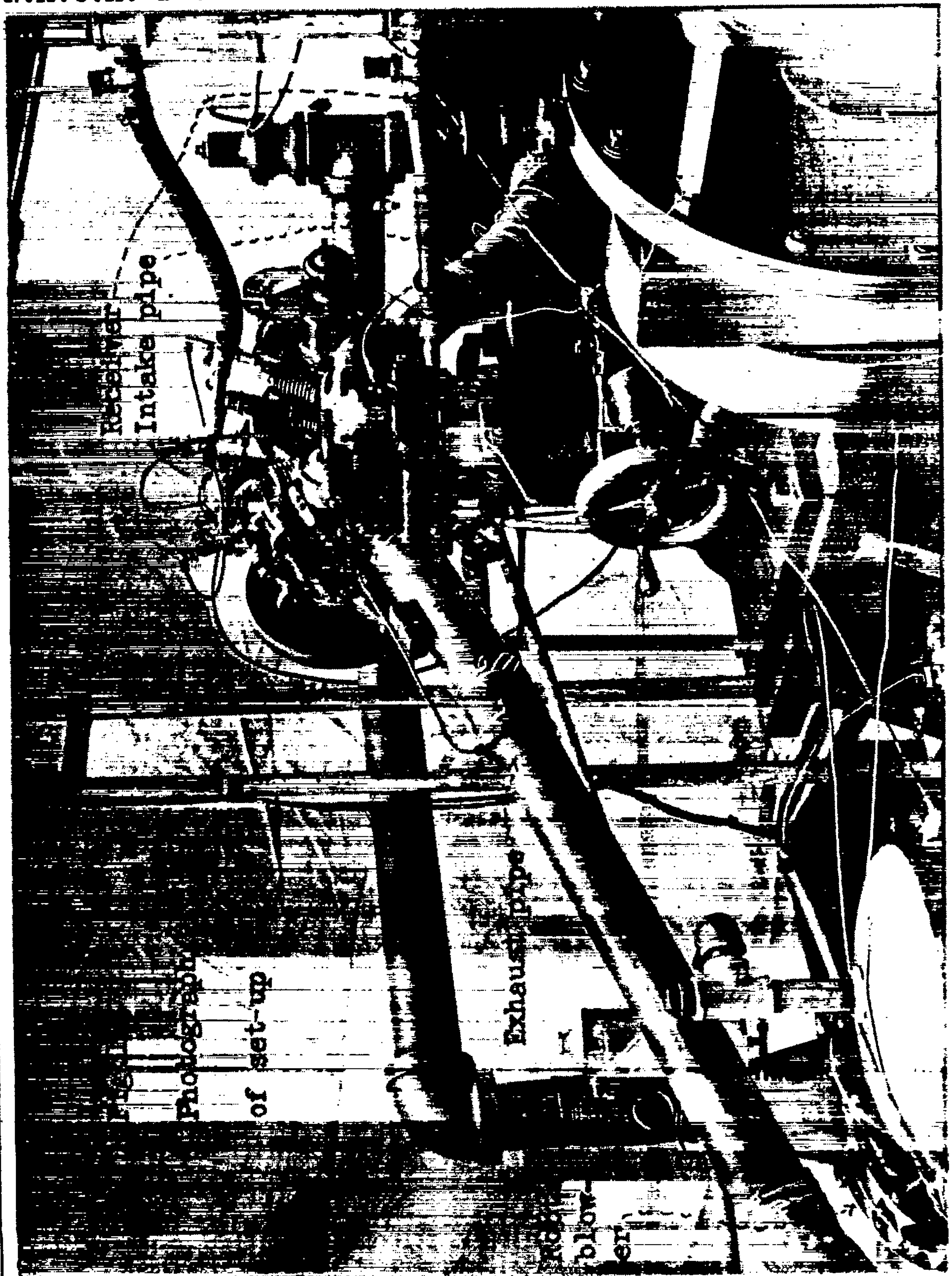
N, = engine r.p.m.

Volumetric efficiency (corrected for clearance volume compressions) $= \dfrac{W\ V_2}{\left(\dfrac{D}{1728}\right)\left(\dfrac{N}{2}\right)\left(1 - \dfrac{P_2 - P_1}{P_1\ r}\right)}$

W, = pounds of air per minute.

V_2, = specific volume of air at supercharger pressure and temperature.

r, = compression ratio.



Photograph of set-up

Note:

Top center is always at intersection of lift curves.

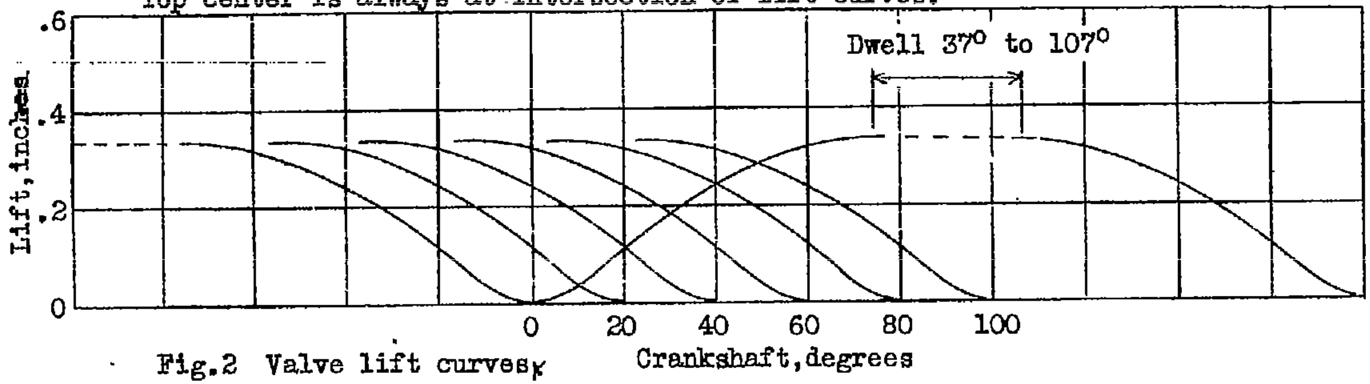


Fig.2 Valve lift curves

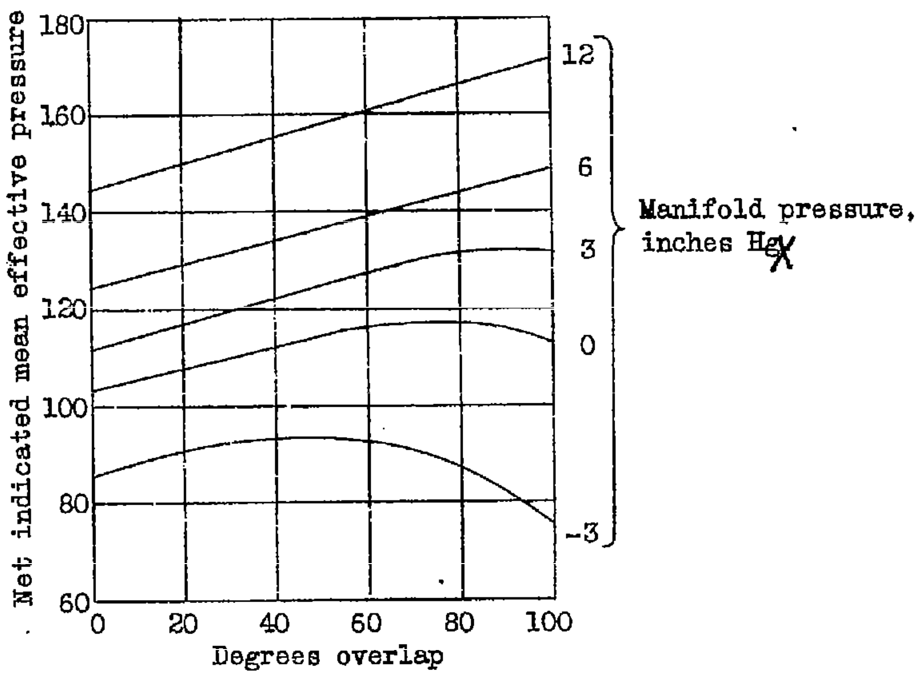


Fig.3 Variation of net indicated mean effective pressure with overlap

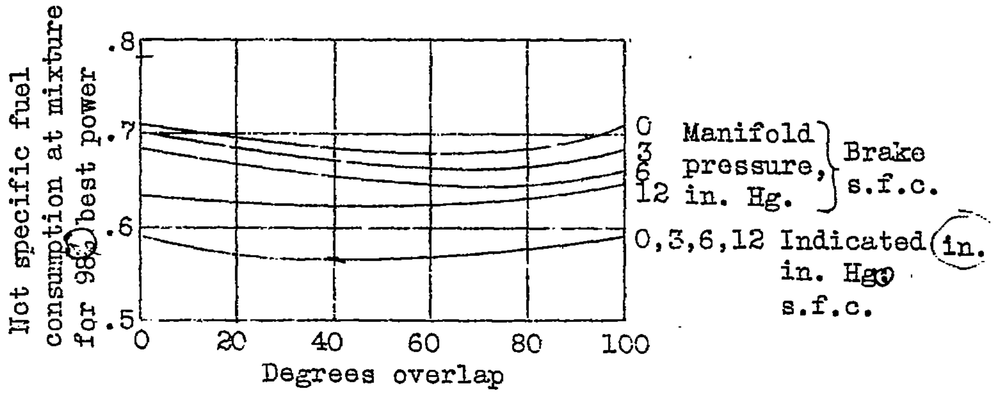


Fig.4 Variation of net specific fuel consumption with overlap.

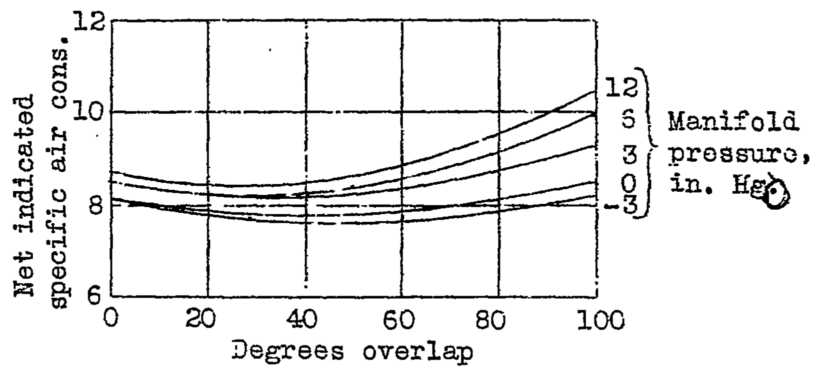


Fig.5 Variation of net indicated specific air consumption with overlap.

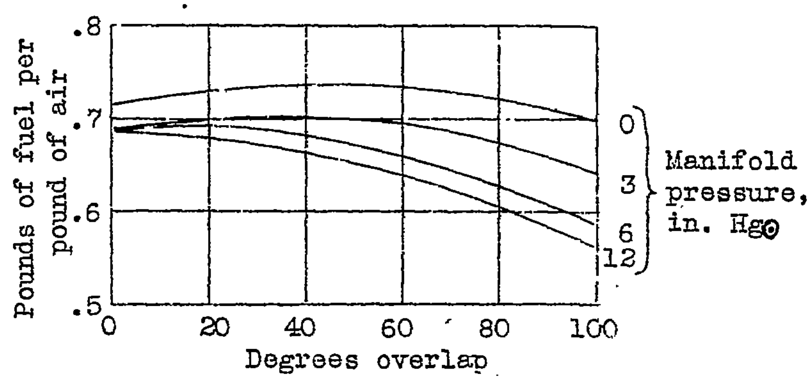


Fig.6 Variation of fuel-air ratio for 98% maximum power with overlap.

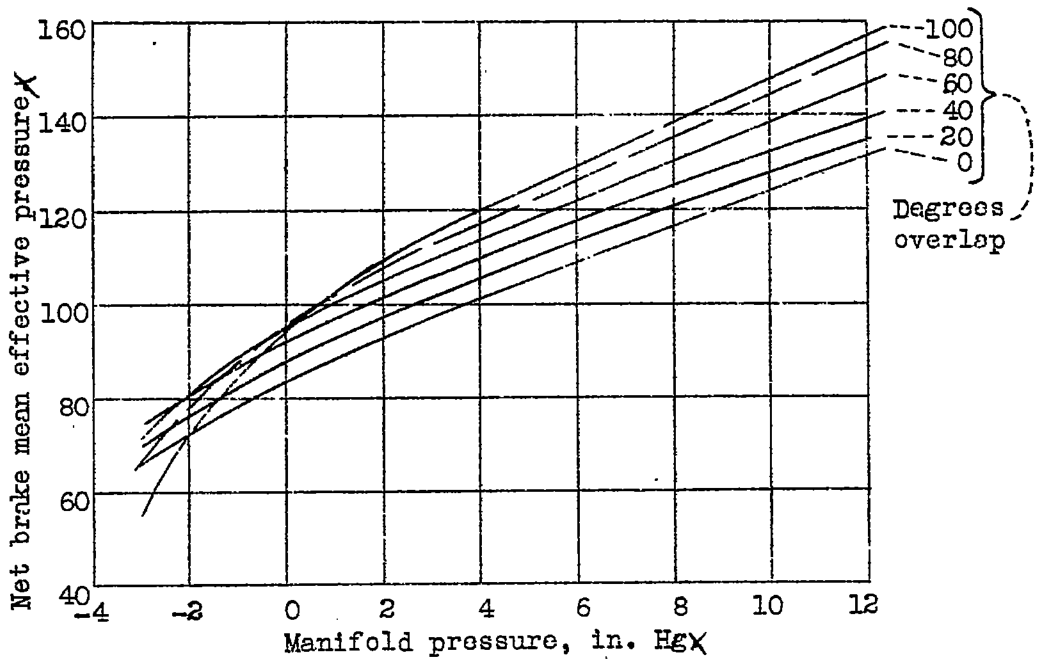


Fig. 7 Variation of net brake mean effective pressure with manifold pressure

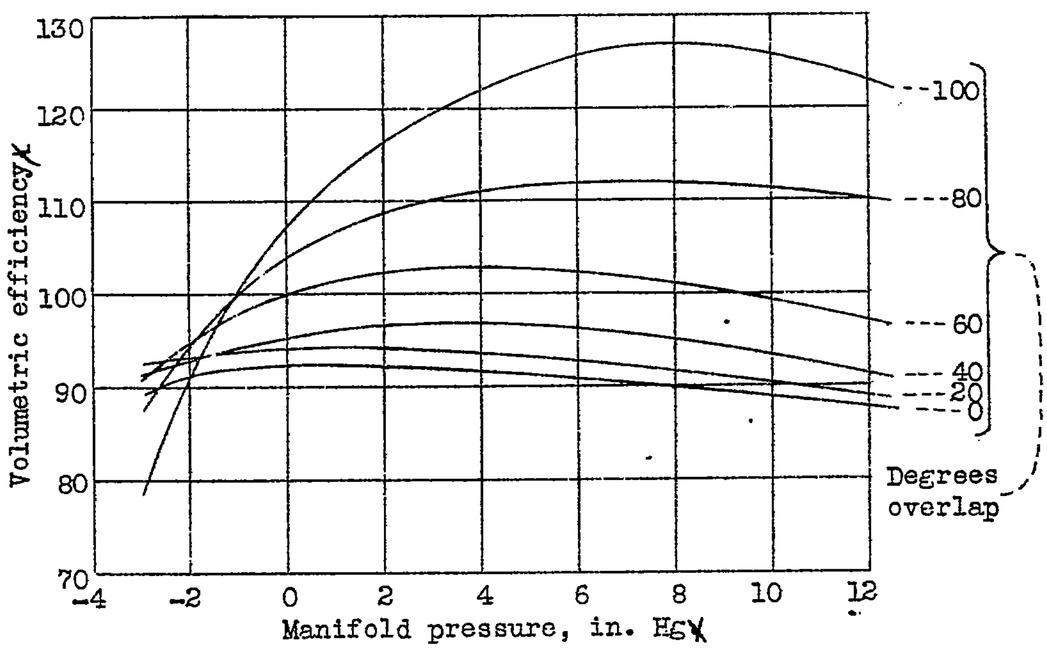


Fig. 8 Variation in volumetric efficiency with overlap efficiency based on air at intake pressure and temperature and corrected for compression of residual products

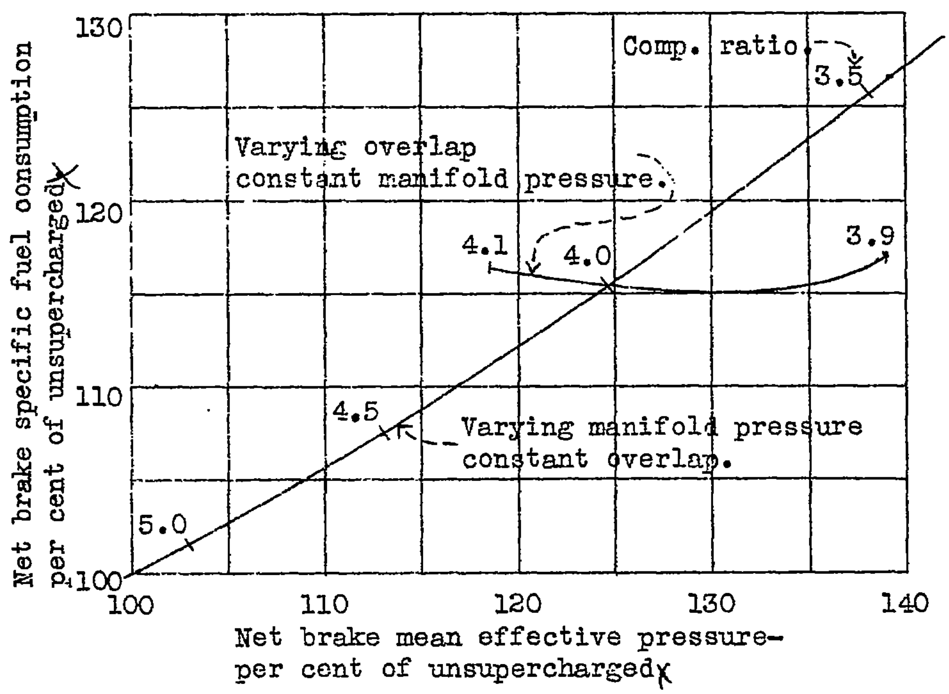


Fig. 9 Variation in net brake specific fuel consumption as supercharger pressure is increased at highest useful compression ratio for each pressure. (40° overlap)

Variation in net b.s.f.c. as overlap is increased at constant supercharger pressure and at h.u.c.r.